6x3 Microstrip Beam Forming Network for Multibeam Triangular Array

A. Novo García[1], M. Vera-Isasa[1], Javier García-Gasco Trujillo[2], and M. Sierra Pérez[2]
[1]Universidad de Vigo, Spain
[2]Universidad Politécnica de Madrid, Spain

Abstract- A six inputs and three outputs structure which can be used to obtain six simultaneous beams with a triangular array of 3 elements is presented. The beam forming network is obtained combining balanced and unbalanced hybrid couplers and allows to obtain six main beams with sixty degrees of separation in azimuth direction. Simulations and measurements showing the performance of the array and other detailed results are presented.

1. INTRODUCTION

Nowadays, earth stations which integrate the ground segment in satellite communications use to be based on large reflector antennas for downloading data from the satellites. These reflector antennas, however, have some drawbacks regarding their high cost, mechanical complexity and low flexibility. For this reason, other antenna configurations have been studied.

Antenna arrays have some advantages over large dishes: capability to track several satellites simultaneously, higher flexibility, modularity and lower production and maintenance cost are the most important of them. GEODA [1] is a smart dome antenna composed of triangular phased arrays designed to receive signals from low orbit satellites. Its structure is shown in Fig. 1. It is composed of two different parts: a 1.5 meters high cylinder and a semisphere situated upon it. For the construction of these two pieces 60 triangular panels are required, each of them composed of 15 subarrays of three circular patches referred to as cells.

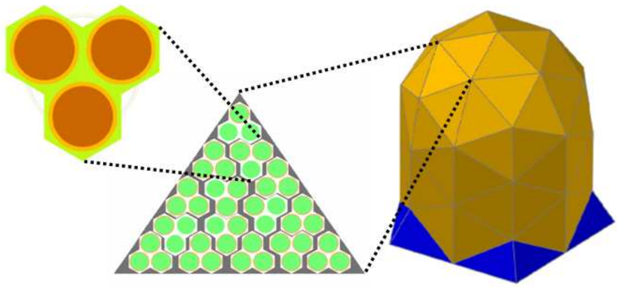


Figure 1

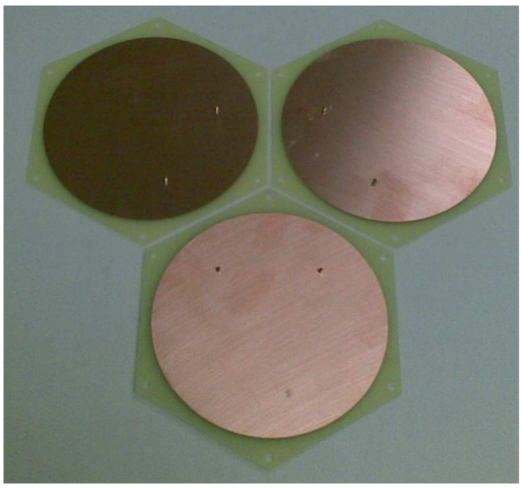


Figure 2

2. RADIATING ELEMENT

The basic radiating element of the structure is a circular patch. The patches are arranged in cells of three elements, as was explained in previous section. We can see in Fig. 2 an image of one of these cells.

The radiation of any of these cells will be given by the array factor of the set, whose expression is

$$AF(\theta,\phi) = \sum_{n=1}^{3} A_n\, e^{j[k\, a\, \sin\theta \cos(\phi-\phi_n)+\alpha_n]} \tag{1}$$

where k is the wave number, a is the distance from the center of each patch to the center of the array, θ is the elevation angle, φ is the azimuth angle, $\varphi_n = 2\pi\ (n/3)$ is the angular position of the element n in the plane which contains the three patches and A_n and α_n are the amplitude and phase of the excitation for this element. The working frequency for the cells will be f_0 = 1.7 GHz and the separation between patches is d = 10 cm.

If the cell is properly fed, we could obtain main beams in the azimuth directions φ = 0º, 60º, 120º, 180º, 240º and 300º [2]. Phase relations needed to accomplish this are shown in table 1.

Phase relation	Beam azimuth direction
$\alpha_1 = \alpha_2 = \alpha_3 + 120°$	$\varphi = 0°$
$\alpha_2 = \alpha_3 = \alpha_1 + 120°$	$\varphi = 120°$
$\alpha_3 = \alpha_1 = \alpha_2 + 120°$	$\varphi = 240°$
$\alpha_1 = \alpha_2 = \alpha_3 - 120°$	$\varphi = 180°$
$\alpha_2 = \alpha_3 = \alpha_1 - 120°$	$\varphi = 300°$
$\alpha_3 = \alpha_1 = \alpha_2 - 120°$	$\varphi = 60°$

Table 1

3. BEAM FORMING NETWORK

The design is based on Butler networks [3], but with an odd number of inputs and outputs, as Shelton studied [4, 5]. In this paper, we use a set of equations which provide a relation between the lengths of the connection transmission lines in the network and the desired phase relation between the outputs [2]. These equations allow a flexible calculation of the transmission lines, and so a more flexible design of the BFN.

The design of a 3x3 lossless beam forming network has been carried out in [2]. The resulting structure (from now board A) is shown in Fig. 3 and it is composed by two balanced hybrid couplers (in red squares) and one unbalanced (in blue square). This network is able to provide phase relations at outputs suitable of obtaining radiation beams in the directions φ = 0º, 120º and 240º.

With the use of a $4\pi/3$ fixed phase shifter, we can obtain a second network which can be used to get three simultaneous beams in the complementary directions of the first network, that is, in the azimuth directions φ = 60º, 180º and 300º. Both circuits can be combined with three microstrip Wilkinson combiners at each of the outputs of the individual boards, following the scheme shown in Fig. 4, and this way a 6 inputs 3 outputs BFN is obtained. With this scheme each of the inputs will provide one phase relation at the outputs which can be used to obtain a beam in a given direction once these outputs are connected to the cell of three patch antennas.

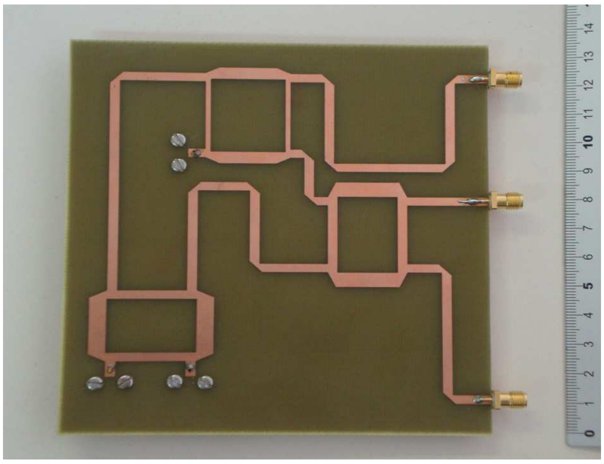


Figure 3. Board A

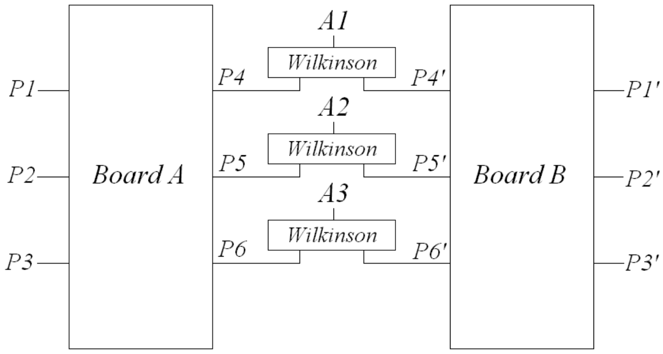


Figure 4. BFN

4. RESULTS

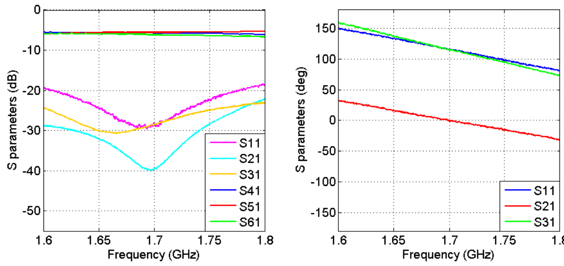
Results obtained with *IE3D* software at 1.7 GHz are shown at Table 2 for each input of the 6x3 design. Each row shows the S parameters for each of the inputs shown in the first column. Phase relations for inputs P1, P2 and P3 are suitable of providing main beams in azimuth directions φ = 240º, 120º and 0º, while phase relations for inputs P1', P2' and P3' can be used to point the main beam in directions φ = 300º, 60º and 180º, respectively.

	P1(dB)	P2(dB)	P3(dB)	P1'(dB)	P2'(dB)	P3'(dB)	A1(dB|deg)	A2(dB|deg)	A3(dB|deg)
P1	-25.11	-36.73	-30.25	-85.99	-52.96	-80.21	-8.78|-102.4	-8.66|141.3	-9.05|-101.4
P2	-36.73	-24.59	-30.4	-52.96	-77.65	-88.28	-8.98|-106.2	-9.47|15.2	-9.60|14.72
P3	-30.25	-30.4	-29.02	-79.62	-89.03	-53.54	-9.98|162.7	-9.20|164.6	-8.99|46.55
P1'	-85.99	-52.96	-79.62	-24.42	-42	-30.5	-8.79|-102.6	-8.67|141.2	-9.21|138.2
P2'	-52.96	-77.65	-89.03	-42	-25.49	-32.19	-8.97|-106.4	-9.45|15.05	-9.82|-105.9
P3'	-80.21	-88.28	-53.54	-30.5	-32.19	-30.98	-9.98|162.6	-9.21|164.4	-9.15|-74.38

Table 2

A prototype of board A was built (Fig. 3) and performance was measured for a signal at each of the inputs as can be shown in Fig. 5, where P1, P2 and P3 are signals at input ports, and P4, P5 and P6 are signals at output ports. Phase relations at outputs agree with those presented in the first three rows of Table 1. The measured performance of Board B is also shown in Fig. 5, where it can be seen that phase relations coincide with the three final rows of Table 1.

The measured normalized radiation pattern in dB when each one of the inputs of the network is selected is shown in Fig. 6. If signal is at input 1, the main radiation beam points at φ = 240º; if it is at input 2, the main beam direction is φ = 0º; if it is at input 3, we can see the main beam pointing at φ = 120º.



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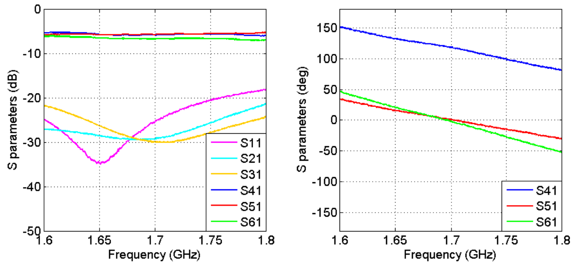
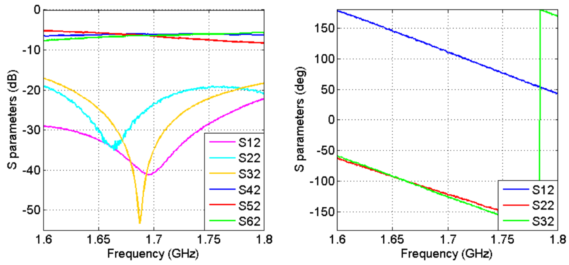
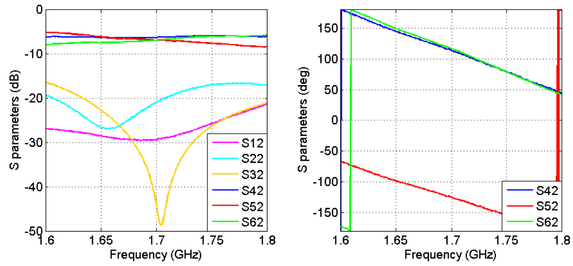


d)



b)



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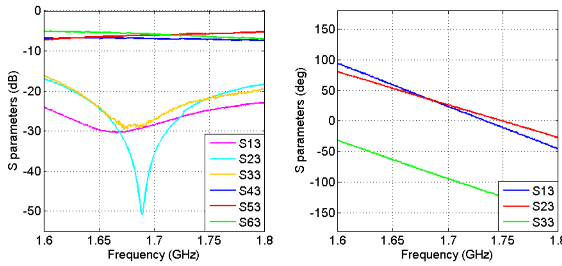
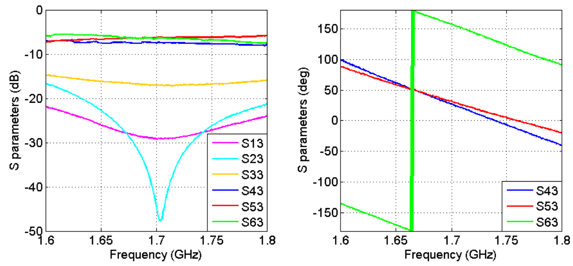
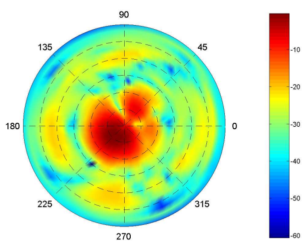


c)

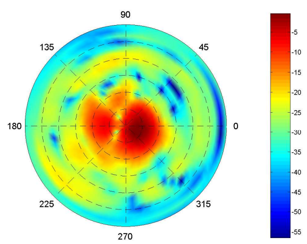


f)

Figure 5. Measurements for board A: a) Input 1, b) Input 2, c) Input 3 and measurements for board B: d) Input 1, e) Input 2, f) Input 3



a)



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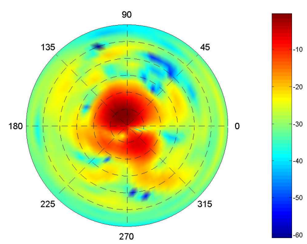

c)

Figure 6. Radiation diagram with board A feeding a cell: a) Input 1, b) Input 2, c) Input 3

The elevation pattern is similar for the six beams. In Fig. 8 it is shown for φ = 120º.

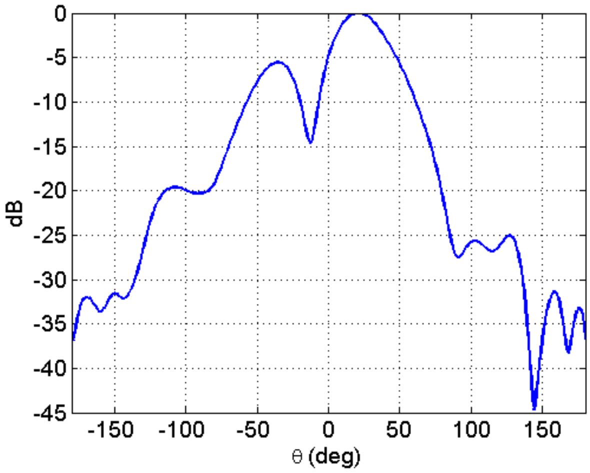

Figure 8

5. CONCLUSIONS

A 6x3 beam forming network which can provide the phase relations needed to feed a circular array of 3 elements to obtain 6 simultaneous beams is presented in this paper. The network is composed of two 3x3 boards which have been built and measured, showing the desired performance at the working frequency. The combination of such boards with three Wilkinson dividers presented in this paper has been simulated and has shown the expected magnitude and phase relations at outputs.

ACKNOWLEDGEMENT

This work was supported by MCI under TEC2008-06736-C03-02.

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